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NOTES ON THE EFFECTS OF HUMAN
ACCELERATION TOLERANCES ON
DESIGN FOR THE TERRAIN FOLLOWING
AIRCRAFT

DOUGLAS AIRCRAFT DIVISION · LONG BEACH, CALIFORNIA

DOUGLAS

DOUGLAS AIRCRAFT COMPANY, INC.

EL SEGUNDO DIVISION

Engineering   DEPARTMENT

REPORT NUMBER

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Notes on the Effects of Human Acceleration
Tolerances on Design for the Terrain Following
Aircraft

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REVISIONS

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2.0   INTRODUCTION

Under conditions of terrain following flight in the Mach 1 speed region, the physiological limitations of the pilot may pose a restriction as to how close the terrain following can be executed.

2.1   Definition of the Problem

To investigate this problem some calculations have been made to see what kinds of restrictions tolerances to both negative and positive g-forces will impose on low level high speed flight. Only a simplified model has been considered, namely: the airplane is considered to be a rigid structure flying at a constant average velocity and moving in only one plane. Evasive movements are considered to be flown in a sine wave pattern in the vertical plane. With these restrictions it is necessary to consider only the forces normal to the center line of the aircraft.

$$F_c = \frac{MV^2}{R} = \frac{WV^2}{gR}$$
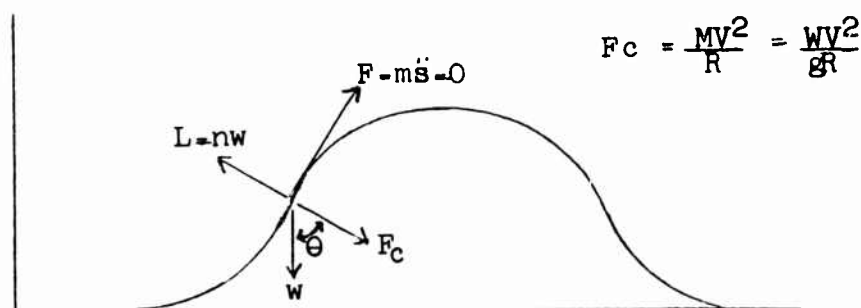
Summing these forces radially.

$$\Sigma F_R: \quad nw = F_c + w\cos\theta$$

$$nw = \frac{wv^2}{GR} + w\cos\theta$$

or

$$n - \frac{v^2}{GR} + \cos\theta$$

where w = vehicle weight, n = load factor
R = radius of turn, V = velocity, g =
acceleration due to gravity. θ = pitch angle,
s̈ = acceleration on path, F_s = net force and
F_c - the total centrifugal force acting normal
acting normal to the direction of the airplane.

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3.0   DISCUSSION

The load factor (g force) exerted on the pilot
during any longitudinal maneuver must of course be
restricted to the physiological tolerance of the
pilot. This in turn defines the radius of the flight
path that can be flown. Since in terrain following
peaks of different heights may be encountered and
since the radius of pullup is defined by the physio-
logical tolerance of the pilot, it is necessary to
know how far from different peak heights a pilot must
begin his maneuver to avoid collision.

3.1   SIMPLIFYING ASSUMPTIONS

For purpose of simplifying calculations it
was assumed that a circular flight path was
flown at constant velocity.   This would be rough-
ly comparable with the major part of the path
attempting to follow the third quarter wave of a
sinisoidal flight path.

$$\Delta H = h_{max} - h$$

$$h_{max} = R$$

$$\Delta H = R - h$$
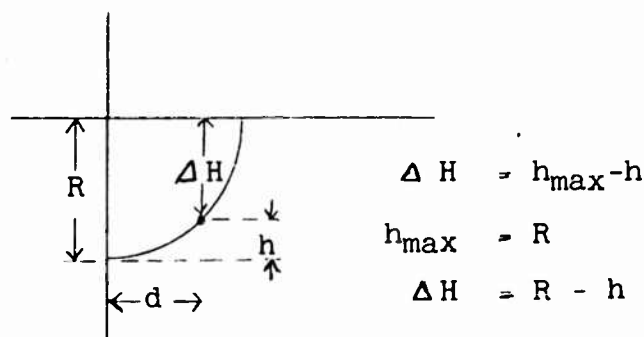
For a circle
$$x^2 + y^2 = R^2$$

or in terms of the model
$$d^2 + (\Delta H)^2 = R^2$$

or
$$d^2 + (R-h)^2 = R^2$$

then
$$d = \sqrt{R^2 - (R-h)^2} = \sqrt{h(2R-h)}$$

FORM 30-250
(7-51)

It is possible from these models to calculate
the radius of pull-up permitted for a given g-
loading and to also determine the distances re-
quired using this radius to avoid peaks of
different evaluations.

3.2   POSITIVE G-FORCE LOADING AND TOLERANCE

Blackout thresholds for unprotected pilots
vary with the individual over a wide range.
However, with reasonable selection of personnel
it would appear that the unprotected pilot might
sustain a maximum of 3g positive without undue
stress.

The positive g-force loading permitted on
a pilot can be increased by the use of pressure
suits. The use of such suits improves g-tolerance
of a pilot from 1.5 to 2-g. If the pilot is
selected properly it appears that a g-loading of
5g positive is not an unreal figure for maximum
permitted g for the protected pilot.

Assuming these tolerance values, minimum radii
have been calculated for flight at 0.95 Mach and
for 1.2 Mach.   Using these radii the distance at
which pullups must be started for several obstacle
heights has been calculated for both the protected
and unprotected pilot.   These values are given
in Table 1 and are shown graphically in Figures 1
and 2.

3.3   NEGATIVE G-FORCE LOADING AND TOLERANCE

In passing over an obstacle there will be a
change from positive to negative g exerted on the
pilot.   Physiological tolerance to this kind of
maneuver has not been determined hence cannot be
assessed in this discussion.

After passing over an obstacle, any attempt
without large lateral changes, to follow the terrain
will impose negative g on the pilot. Much less is
known about the physiological effects and permitted
loading for negative g than there is for positive g.
While even 1g negative is uncomfortable after even
moderate times (i.e., standing on your head), it
appears that for the times involved in the present
calculations (1 to 10 sec.), a pilot could sustain

TABLE I

Distance and Time Required to Avoid Obstacles
Of Different Heights

M 0.95				M 1.2	
h(ft)	d(ft)	time(sec)	h(ft)	d(ft)	time(sec.)
Unprotected pilot: Maximum 3g positive assumed					
200	2,150	2.03	200	2,719	2.03
400	3,027	2.85	400	3,836	2.86
600	3,692	3.48	600	4,685	3.50
800	4,243	4.00	800	5,395	4.03
1,000	4,723	4.45	1,000	6,014	4.49
2,000	6,528	6.15	2,000	8,390	6.26
4,000	8,788	8.28	4,000	11,520	8.60
8,000	11,060	10.42	8,000	15,280	11.40
G-suit protected pilot; Maximum 5g assumed					
200	1,662	1.57	200	2,102	1.57
400	2,333	2.20	400	2,960	2.20
600	2,836	2.67	600	3,608	2.69
1,000	3,605	3.40	1,000	4,610	3.44
2,000	4,900	4.62	2,000	6,373	4.76
4,000	6,320	5.90	4,000	8,555	6.38
7,000	7,000	6.60	7,000	10,350	7.72
8,000	7,000	6.60	8,000	10,700	7.98

TABLE II

Distance and Time Required to Recover Low Level Flight
Altitude After Avoidance of Obstacles of Different
Heights.   (Maximum negative 2g assumed)

M 0.95			M 1.2		
h(ft)	d(ft)	time (sec)	h(ft)	d(ft)	time (sec)
200	2,637	2.48	200	3,340	2.49
400	3,720	3.51	400	4,714	3.52
600	4,540	4.28	600	5,763	4.30
800	5,227	4.93	800	6,643	4.96
1,000	5,830	5.49	1,000	7,413	5.53
2,000	8,120	7.65	2,000	10,385	7.75
4,000	11,130	10.49	4,000	14,410	10.75
8,000	14,680	13.84	8,000	19,590	14.62

FORM 30-250M
(7-51) E. A. LITHO

2g negative without physiological damage.   Un-
fortunately there are no protective devices
that can be used to increase pilot tolerance to
negative g.   This physiological limit then de-
fines the over-shoot that will occur after clear-
ance of any obstacle. Assuming a permitted 2g
negative tolerance, calculations of this "over-
shoot" have been made for several obstacle heights.
These values are given in Table II and shown
graphically in Figure 3.

3.4   POSITIVE G-FORCE LOADING AND VISION

Repeated application of g forces results in
other physiological modifications that may effect
design decisions. Among the physiological functions
that are altered by g stress is vision. The pilot
need not be exposed to g levels that result in"dim-
out" or blackout to show visual responses to accel-
eration.   While these visual effects have not been
studied extensively to date, there is sufficient
data to show that a problem exists.   W. J. White
(1956, et sub) and others have examined the effects
of positive acceleration on the relationship between
illumination and instrument reading and also the
variation in absolute visual thresholds during
accelerative stress. In the first study the total
error increased directly as a function of g (up to
4g) and inversely as a function of brightness at
illumination levels of 0.042 millilamberts and
below.   Warrick and Lund (1946) had previously shown
that errors in instrument reading increased from 18
percent at 1.5g to 24 percent at 3g.   White has also
shown that acceleration levels of 3 and 4g approxi-
mately doubles and triples foveal threshold, and the
threshold levels in peripheral vision triple at 3g
and quadruple at 4g.   Both thresholds are effected by
g levels as low as 2g.   These effects are compensated
for in part by use of anti-g suits.

3.5   NEGATIVE G-FORCE LOADING AND VISION

There appears to be very little systematic data
on the effects of negative g on vision. There have
been cases reported of blurred vision at 2g negative
and doubling of vision at 3g negative. Some pre-
liminary studies by Sieker (1952 would indicate that
the use of counterpressure in a full pressure helmet

may help to alleviate these systems, however, this observation has not been confirmed or investigated and may be related to the fact that the counter pressure protects against the mechanical deformation of the eyeball which would effect vision without influencing tolerance to negative g.

Additional studies of the effects of g loading on visual functions are needed before an accurate assessment of the seriousness of the problem can be made.
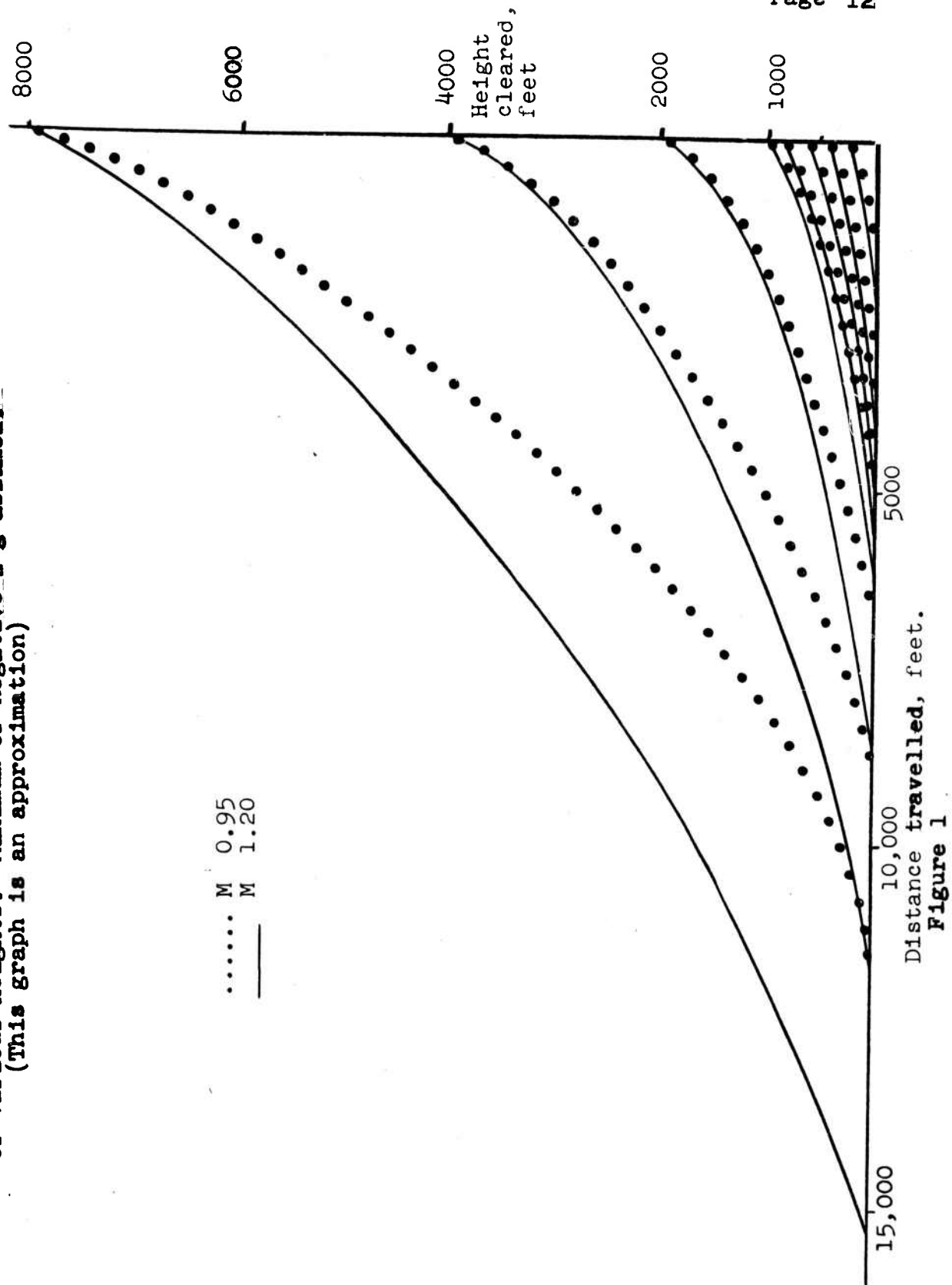
4.0   CONCLUSIONS

Accelerative forces acting on the pilot serve as
a severe limitation on low level, high speed terrain
following operations.   The physiological restrictions
imposed by acceleration forces essentially define the
flight path permitted and hence restrict the altitudes
that can be maintained over any defined terrain. While
some benefit can be derived by the use of anti-g suits
for positive g forces, the physiological limitations
are not apparent when an attempt is made to control over-
shoot after passing over a barrier.   At this time
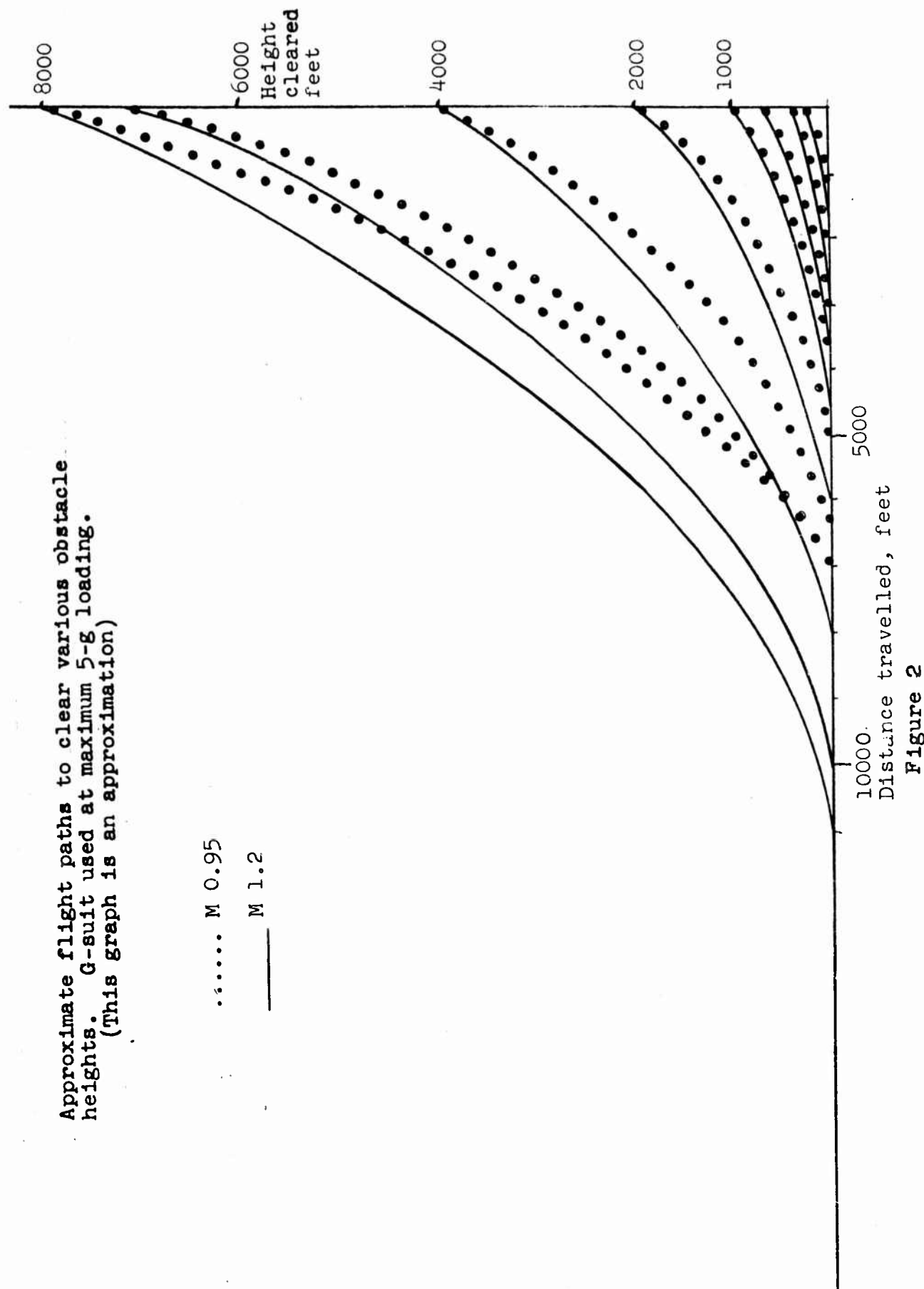negative g forces are applied to the pilot.

Some evidence is available to show that repeated
application of g-forces may effect physiological para-
meters other than tolerance and may thus be of importance
in defining performance characteristics or limits. More
work must be done on the effects of g-loading on these
parameters before a reasonable assessment can be made.

5.0   REFERENCES

1. Dixon, F. and Patterson, J. L.   Determination of Accelerative Forces Acting on Man in Flight and in the Human Centrifuge. US School of Av. Med. Project No. NM 001 059.04.01

2. Edeberg, R. Henry, J. P., Macrolek, J.A. Salzman, E. W. and Zuidena, G. D.   Comparison of Human Tolerance to Accelerations of Slow and Rapid Onset.   J. Av. Med. 27: 482(1956)

3. Henry, J. P.   Studies of the Physiology of Negative Acceleration.   Air Materiel Command Wright-Patterson AFB Ohio.   AF Tech Report 5953. 1950.

4. Lewis, D. H., An Analysis of Some Current Methods of G-Protection, American I of Aviation 26:479(1955)

5. Miller, H., Riley, M. B., Bondurant, Sand Hiatt, E.P. The Duration of Tolerance to Positive Acceleration WADC Wright Patterson, Ohio, WADC Tech. Report 58-635.

6. Sicker, H. O.   Devices for Protection Against Negative Acceleration   WADC Wright-Patterson AFB Ohio.   WADC Tech Report 52-86, Par 1, 1952

7. Warrick, H. J. and Lund, D. W.   The Effect of Moderate Positive Acceleration on Ability to Read Aircraft Type Instrument Dials.   Air Materiel Command, Wright-Patterson AFB, Ohio, USAF Memo Report No. TSEAA 694-10. (1946)

8. White, W. J.   Acceleration and Vision, WADC Wright Patterson, Ohio   WADC Tech Report 58-333 (1958)

9. White, W. J.   Variation in Absolute Visual Thresholds During Accelerative Stress,   WADD Wright-Patterson, Ohio,   WADD Tech Report 60-34, 1960.

10. White, W. J. and Riley, M. B.   The Effects of Positive Acceleration on the Relative Between Illumination and Instrument Reading,   WADC Wright-Patterson AFB, Ohio, WADC Tech Report 58-332, 1958.

11. White, W. J. and Torne, W. R.   The Effects of Gravitational Stress Upon Visual Acuity, WADC, Wright-Patterson AFB, Ohio, WADC Tech Report 56-247, 1956.

Approximate flight paths after clearance of obstacles
of various heights. Maximum of negative 2-g assumed.
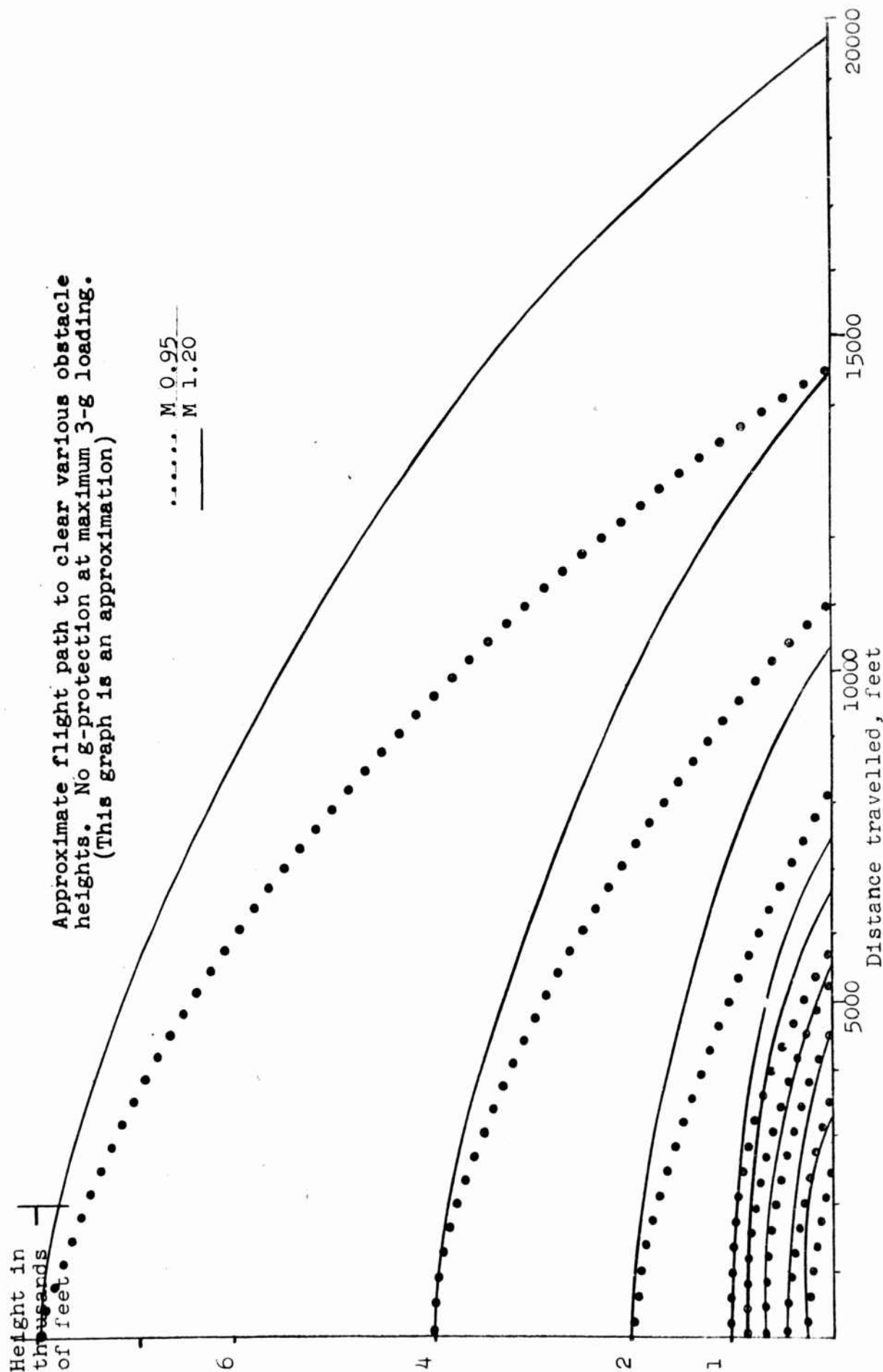(This graph is an approximation)

...... M 0.95
——— M 1.20

Height cleared, feet

8000

6000

4000

2000

1000

Distance travelled, feet.

15,000

10,000

5000

Figure 1

Approximate flight paths to clear various obstacle heights. G-suit used at maximum 5-g loading. (This graph is an approximation)

...... M 0.95

———— M 1.2

Height cleared feet

8000

6000

4000

2000

1000

5000

10000.
Distance travelled, feet

Figure 2

Approximate flight path to clear various obstacle heights. No g-protection at maximum 3-g loading. (This graph is an approximation)

Figure 3